Aluminum is expected to remain the core material for many critical applications such as aircraft and automobiles. This is due to the high resistance to different environmental conditions, desired and manageable mechanical properties, as well as high fatigue resistance. Aluminum nanocomposites such as AA6061/Al_2O_3 can be made in many ways using a liquid metallurgy method. The main challenges for this method in the production of nanocomposites are the difficulties of achieving a uniform distribution of reinforcing materials and possible chemical reactions between the reinforcing material and the matrix. For structural applications exclusive to aerospace sectors. The growing cost-effective nanocomposites mass production technology with essential operational and geometric flexibility is a big challenge all the time. Each method of preparing AA6061/Al_2O_3 nanocomposites can provide different mechanical properties. In the present study, nine nanocomposites were prepared at three stirring temperatures (800, 850, and 900 °C) with the level of Al_2O_3 addition of 0, 5, 7, and 9 wt %. The results of tensile, hardness and fatigue tests revealed that the composite including 9 wt % Al_2O_3 with 850 °C stirring temperatures has the best properties. It was also revealed that the 850 °C stirring temperature (ST) with 9 wt % Al_2O_3 composite provide an increase in tensile strength, VHN and reduction in ductility by 20 %, 16 % and 36.8 % respectively, compared to zero-nano. Also, the fatigue life at the 90 MPa stress level increased by 17.4 % in comparison with 9 wt % nanocomposite at 800 °C (ST). Uniform distributions were observed for all nine microstructure compositions

Keywords: 6061 aluminum alloy, Al_2O_3 nanoparticles, nanocomposites, stirring temperatures, stir casting method, mechanical and fatigue properties

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DEVELOPMENT IN MECHANICAL AND FATIGUE PROPERTIES OF AA6061/AL_2O_3 NANOCOMPOSITES UNDER STIRRING TEMPERATURE (ST)

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1. Introduction

From decades ago, the effectiveness of materials improved, new forms have played a key role in the development of science and technology. Advances in physics and technology are difficult without the use of advanced effective materials. To meet their needs, the researchers manufactured and handled materials in the development process. However, an appropriate correlation has not been settled between the properties of a quantity with materials of nanomaterials size. Thus, in current technology researchers are repetitively researching, investigating and trying to get used to new innovative materials. And the necessary scientific research has been conducted related to the improvement of mechanical properties and the factors that affect them, especially stirring temperature and specific amounts of metal nanoparticles added to alloys.

2. Literature review and problem statement

There are many investigations dealing with several aspects related to improving mechanical properties and factors such as stirring temperature, stirring time and particle distribution, which can affect the material properties. Nanocomposites were synthesized by the method to manufacture nanoparticles evenly distributed in metallic matrix composites. This produces a significant improvement in Young's modulus and hardness due to the addition of a low weight fraction of A nanometric [1]. The influence of using Al_2O_3, TiO_2, and ZrO_2 nanoparticles with a size of 40 nm on a base metal matrix (A356 aluminum cast alloy) was studied in [2, 3]. With various fraction ratios ranging from 0 % to 5 %, they were stirred in the A356 matrix, by weight at variable stirring speeds varying from 270 to 2150 rpm in both the semisolid of 600 °C and liquid of 700 °C states applying a fixed stirring time of a minute. This investigation presented that the properties of nano-reinforced castings were improved for the castings applying Al_2O_3, TiO_2, and ZrO_2 effected in the semi-solid state at 600 °C by a 2.0 weight % Al_2O_3 and 3.0 weight % TiO_2 or ZrO_2 at 1500 rpm stirring speed. These studies introduce a new concept of refining and improving the properties of cast aluminum alloys through the addition of nanoparticles, where multiple nanoparticles were used and many variables, including the mixing speed and the time required for that.

Furthermore, [4] investigated the influence of adding reinforcements into the metallic matrix on the mechanical properties. The major points derived from this study state that increasing the reinforcement ratio and decreasing the size of reinforcement particles considerably improve the properties of metal matrix composites. In addition, wear resistance and creep have been studied as other important factors that are not often discussed. Increasing the Al_2O_3 fraction reduces the fracture toughness of AMCs. The addition of zircon advances the strength of AMCs. Moreover, in [5], 10 wt % of Al_2O_3 nanomaterial were added to AA6061 in applying the stir casting method for producing nanocomposites. The comparison between 6061 aluminum alloy metal matrix and 10 wt % Al_2O_3 nanocomposites revealed that there is a 12.8 % improvement in the fatigue strength at 10^7 cycles due to 10 wt % nano-reinforcement. The accumulative fatigue life of 10 wt % nanocomposite was improved by 33.37 % and 39.58 % for low-high and high-low loading sequences, respectively. The results showed that the addition of nanomaterials increased the strength of both constant and cumulative fatigue and fatigue life.

Moreover, [6] investigated the influence of pouring temperature of the slurry produced by weak electromagnetic stirring. Also, the morphology and size of the primary particles in the A356 Al alloy were investigated by analyzing the influence of superheat temperature. In this work, they obtained a semi-solid slurry of metal with a particle as a primary phase by utilizing appropriate weak electromagnetic stirring and increasing pouring heat temperature, which produces a low superheat pouring. Moreover, they have concluded that an increment in pouring temperature by 15–35 °C above the liquidus temperature combined with a weak electromagnetic stirring results in the same size and shape properties of the primary phase. The study showed the effect of stirring the alloy mixture and without stirring, and focused on stirring temperatures rather than other properties. Furthermore, [7] examined the influence of stirring speed and pouring temperature on the properties of Al6061-Cu reinforced SiC MMC by the stir casting process. It was observed from scanning electron microscope (SEM) analysis that at a stirring speed of 400 rpm, an improved homogeneity could be achieved evaluated to that of 200 and 600 rpm. The study concentrated on the stirring speed of the alloy, and it was found that at a certain limit, the mechanical properties change drastically in the direction of not getting better. Besides, [8] studied evaluation emphasizes the optimization of stirring speed and pouring temperature for the properties of aluminum metal matrix composites. Several heights of pouring temperatures at a constant pouring speed of 2.5 cm/s were studied as input parameters throughout. The experimental results indicate that a pouring temperature range of 700 °C to 750 °C and 400 to 600 rpm stirring speed offered developed mechanical properties. So, the focus of this analysis is to optimize the pouring speed, the stirring speed and the pouring temperature for mechanical properties. In addition, [9] studied the optimum conditions for preparing composites reinforced with 5 wt % nanoparticles cast at 850 °C. The study concluded that the optimum conditions for the fabrication of composites after several experiments with reinforced nanoparticles cast have homogeneity in the micro-structures and exhibit increased mechanical properties such as hardness and tensile strength. That is why we found that the improvement takes place in a certain percentage, after which these properties change without improvement. [10] prepared Graphene nanoplatelets (GNP)/Acrylonitrile butadiene rubber (NBR) nanocomposites by the solutions mixing method and vulcanized effectively. The results showed that the crosslinking density was enhanced to 42.3 % compared to that of unfilled NBR. The study concluded that the homogeneity of this compound is the most important objective to improve its properties.

Based on previous studies, it can be concluded that the addition of nanocomposite materials in certain proportions with scientific manufacturing methods leads to an improvement of mechanical properties in general. And the current study emphasizes this trend. Hence, in this investigation, an attempt was made for preparing three types of nanocomposites at three stirring temperatures (800 °C, 850 °C, and 900 °C) using the stir casting method. A detailed characterization, including the mechanical and fatigue properties of the three composites, is made and then the comparison is carried out between the prepared nanocomposites with detailed discussions.

3. The aim and objectives of the study

The aim of this study is to determine the effect of stirring temperature (ST) on the AA6061/Al_2O_3 nanocomposite.

To achieve this aim, the following objectives are accomplished:

– to improve the mechanical properties, including the hardness, tensile strength and fatigue strength of 6061 aluminum alloy;

– to prepare nanocomposites at three stirring temperatures with a uniform distribution in certain cases.

4. Materials and methods

6061 aluminum alloy is applied in the present study as it is widely utilized for different purposes in the aerospace and transportation industries. The chemical composition of AA6061 is as follows: Cu 0.31, Mg 0.98, Zn 0.17, Cr 0.22, Ti 0.09, Fe 0.52, Mn 0.11, Si 0.66, and Al balance. The reinforcement nanomaterial Al_2O_3 had a density of 3.62 gm/cm^3 and a particle size between 20 and 30 nm [11].

The stir casting method adopted for fabricating nanocomposites is as follows: AA6061 was cut into cubes with 1 to 2 cm^3, then washed with alcohol and followed by distilled water five times. The washed parts were then dried by the stream of hot air at a temperature of 100 °C, later the dried parts were heated to approximately 200 °C using an electric heater. Argon gas was pumped into the oven and heated to 800, 850 and 900 °C stirring temperature, and preheated the Al_2O_3 particles to 200 °C. Then finally, nanomaterials were added into the molten aluminum alloy with a gas pump. The furnace temperature was initially elevated over the liquid temperature of aluminum about 800, 850, and 900 °C. The first 800 °C, the second sample was heated to about 850 °C and the third sample was mixed at 900±10 °C to melt the aluminum alloy totally and then cooled down just below 650 °C.

The stirring time was designed for 4 minutes at 450 rpm stirring speed. The Al_2O_3 particles were added to the melt in the furnace, and then the mixing temperature was raised to 800 °C±10 °C. The liquid was poured into molds to acquire an aluminum rod for the composites that are shaped in the form of a cylinder of 14 mm external diameter and length of 160 mm. The equipment used for the stir casting method is shown in Fig. 1. Furthermore, Table 1 shows the rule of the mixture using AA6061 as a metal matrix.

Table 1

Rule of the mixture adopted in this work

Al_2O_3 wt %	Al_2O_3 (gm)	AA6061 (gm)	Total nanocomposite (gm)
5 %	50	950	1,000
7 %	70	930	1,000
9 %	90	910	1,000

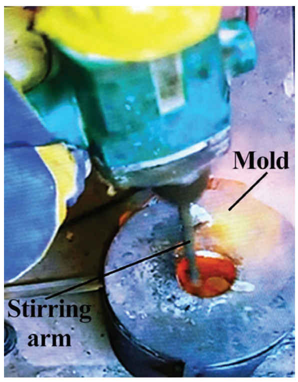


Fig. 1. Manufacturing of composites

The tensile test was carried out using a WDW-100 tensile machine that has a maximum capacity of 100 kN. Eighteen specimens were used from the fabricated round rods of diameter (ϕ)=10 mm and length (L)=160 mm. The deformations were recorded by measuring devices and automatic control. The data were plotted by the plot device. The tensile curves (stress-strain) were employed for predicting the material behavior under different loading.

The standard tensile specimens were made according to the American Society for Testing and Materials (ASTM E8/E8M-09), as shown in Fig. 2, where all the appeared dimensions were measured in (mm). While the tensile test rig is illustrated in Fig. 3. In this paper, Vickers hardness numbers (VHN) were measured using polished samples with different stirring temperatures (800, 850, and 900 °C).

All fatigue tests were carried using a rotating fatigue test rig (ISTRON) as presented in Fig. 3.

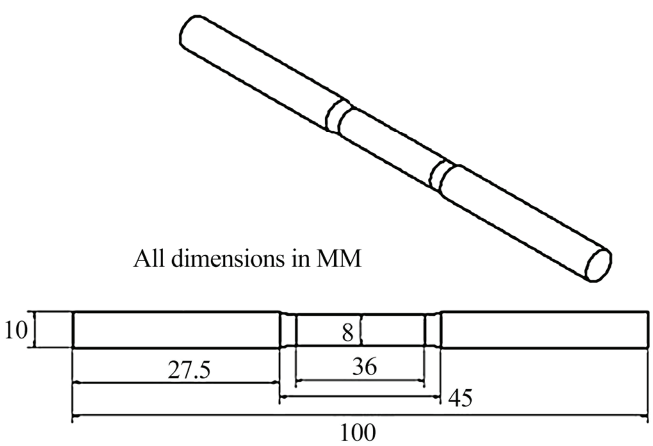


Fig. 2. Tensile specimen according to standard E8/E8M-09 (ASTM)

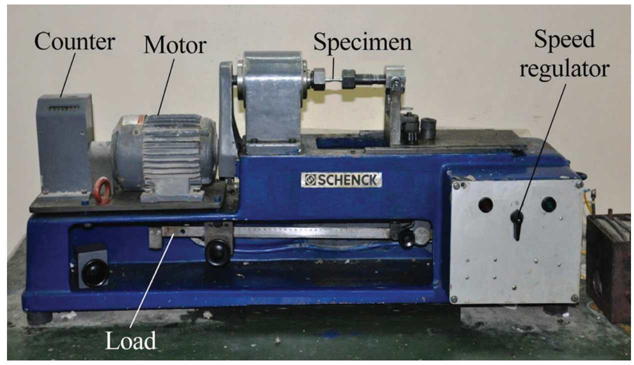


Fig. 3. Rotating Bending Fatigue Machine (ISTRON)

The fatigue samples for testing have been made according to the DIN 50113 specification. A rotating bending fatigue test machine of Schenck type was used to conduct all the fatigue tests.

5. Research results of determining the effect of stirring temperature (ST) on the AA6061/Al_2O_3 nanocomposite

5. 1. Mechanical properties results

The measurements of mechanical properties were carried out at 800, 850, and 900 °C stirring temperatures. Table 2 outlines the results of mechanical properties of AA6061 and nanocomposites with wt % variations of 0, 5, 7 and 9 % Al_2O_3 using stirring temperatures of 800, 850, and 900 °C.

It can be noticed from Table 2 that the mechanical properties of nanocomposites are influenced by stirring temperature and wt % Al_2O_3 nanoparticles. The results of UTS of this investigation applying stirring temperatures of 800, 850, and 900 °C are summarized in Fig. 4–6, respectively. Obviously, the UTS of the nanocomposites increases from 156 to 196 MPa and YS increases from 141 to 164 MPa while the VHN increases from 99 to 118. However, the ductility reduces from 15.2 % to 9.6 % for the best stirring temperature (ST) of 850 °C and 9 wt % of Al_2O_3. Furthermore, an improvement percentage was recorded to be 20.4 %, 14 %, and 19.2 % for UTS, YS, and VHN respectively, while the enhancement percentage in ductility was reported to be 36.8 %. So far, the outcomes are in the same trend as [12]. As they blended AA7075/Al_2O_3 nanocomposites using the stir casting technique at 850 °C stirring temperature with 0, 1, 3, and 5 wt % of Al_2O_3.

The optimal Ultimate Tensile Strength (UTS) of 196.542 MPa and Yield Stress (YS) of 164.435 MPa are obtained from the nanocomposite with 9 % Al_2O_3 at 850 °C and 4 min. stirring time as presented in Fig. 6. The increasing degrees of UTS and YS of 20.4 % and 14 %, respectively, compared to zero-nano (matrix component).

The uniform distribution of Al_2O_3 into a matrix and relatively lower porosity in the casting led to high-density dislocations leading to an enhancement of mechanical properties. It can be concluded that 6061 Al alloy-based composites with 9 % Al_2O_3 possess better mechanical properties. All the fabricated nanocomposites show improvement in hardness and ductility. The 9 % Al_2O_3 composite shows an optimal improvement in hardness and ductility at 850 °C stirring temperature. The hardness of 9 % Al_2O_3 at 850 °C increased by 16 %, while the ductility enhanced by 36.8 %. These findings are somehow aligned with [13], where they fabricated and examined 2024/Al_2O_3 nanocomposites to obtain the improvement in mechanical properties.

Table 2

Results of mechanical properties of AA6061and nanocomposites based on three different stirring temperatures

Al_2O_3, wt %	UTS (MPa)			YS (MPa)			VHN			Ductility		
	800 °C	850 °C	900 °C	800 °C	850 °C	900 °C	800 °C	850 °C	900 °C	800 °C	850 °C	900 °C
zero	151.22	156.75	145.46	137.53	141.44	124.23	92.26	99.74	88.21	16 %	15.20 %	16.40 %
5 %	170.54	182.23	177.28	144.23	147.34	138.77	105.42	108.87	101.23	14.90 %	13.60 %	15 %
7 %	178.56	189.98	176.65	148.54	157.45	150.68	108.23	111.65	106.43	12 %	11 %	14.30 %
9 %	186.23	196.54	181.24	154.68	164.43	160.22	112.67	118.84	109.45	10.70 %	9.60 %	11 %

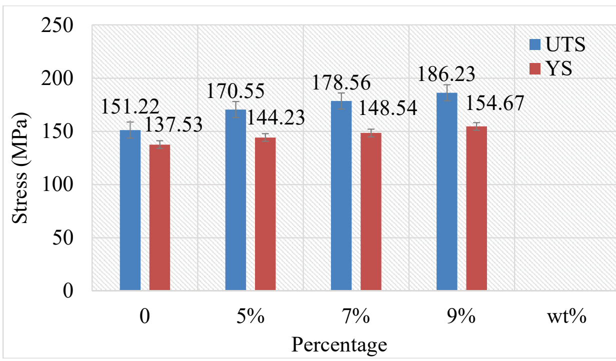


Fig. 4. UTS, YS, with the percentage at stir casting Temp. 800 °C of the weight percentage of Al_2O_3

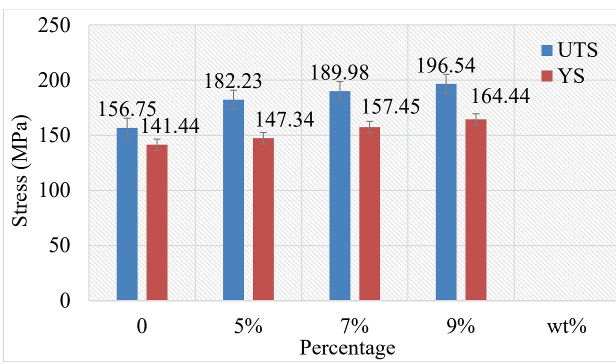


Fig. 5. UTS, YS, with the percentage at stir casting Temp. 850 °C of the weight percentage of Al_2O_3

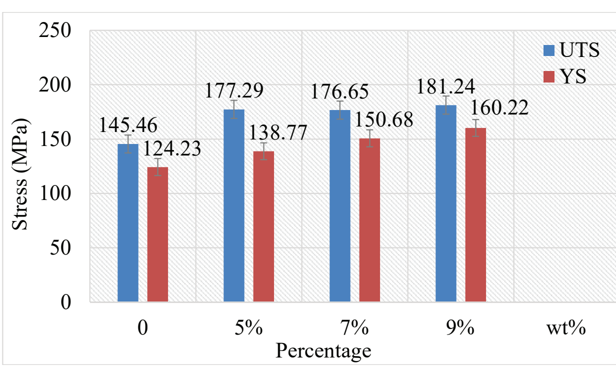


Fig. 6. UTS, YS, with the percentage at stir casting temp. 900 °C of the weight percentage of Al_2O_3

The results of the VHN hardness of the matrix are shown in Fig. 7. Important developments in mechanical properties and hardness were recorded from adding Al_2O_3 in the matrix. The reason could be that Al_2O_3 particles act as obstacles to the motion of dislocations and Al_2O_3 particles work as a barrier to crack initiation and slip band [14, 15]. In addition, Al_2O_3 particles are harder than those of the base metal leading to the improvement of mechanical properties and VHN of the composites. The fairly distributed particles of Al_2O_3 resulted in the development of the mechanical properties of the composites [16].

The results of ductility tests show that an increase in Al_2O_3 leads to ductility reduction. The maximum decrease occurred for the composite including 9 wt % Al_2O_3 achieved at 850 °C stirring temperatures. Once again, the result is confirmed by [17], who have found that increasing the amount of Al_2O_3 improves UTS and VHN. Nevertheless, the ductility tends to reduce, and the peek reduction is obtained at 6 wt % Al_2O_3 with 850 °C stirring temperature. As presented in Fig. 8, the ductility of all the composites drops when increasing the amount of Al_2O_3 compared to that of the matrix material and the maximum reduction occurs in the composite fabricated at 850 °C stir temperature. An improvement in mechanical properties and hardness with a reduction in ductility may be due to the thermal mismatch between the base metal and Al_2O_3 particles [18, 19].

The specimen has a round cross-section and is affected by the employed load from the perpendicular axis to the right side of the workpiece, improving the bending moment. Hence, the surface of the workpiece is under compression and tension stress when it rotates. Three samples were tested for each stress level. The results showed that the samples manufactured at 850 °C (ST) have a longer fatigue life than others, as shown in Table 3. The outcome of these experiments can be applied to the relationship between the stresses used and the number of cycles to failure.

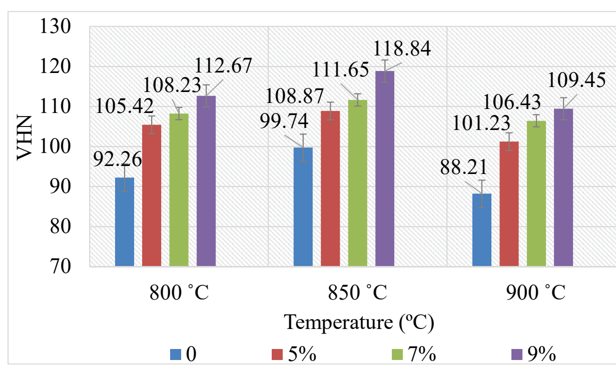


Fig. 7. Vickers hardness results in VHN

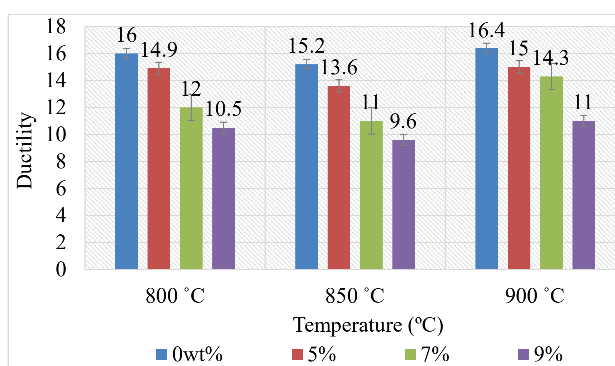


Fig. 8. Ductility varies with stirring temperature at different wt % of Al_2O_3

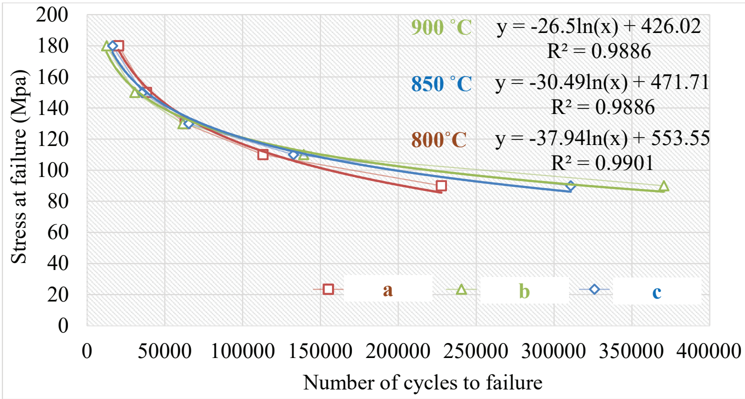


Fig. 9. S-N curves of three cases (800, 850, and 900 °C) of stirring temperatures

Table 3

Comparison between fatigue test results

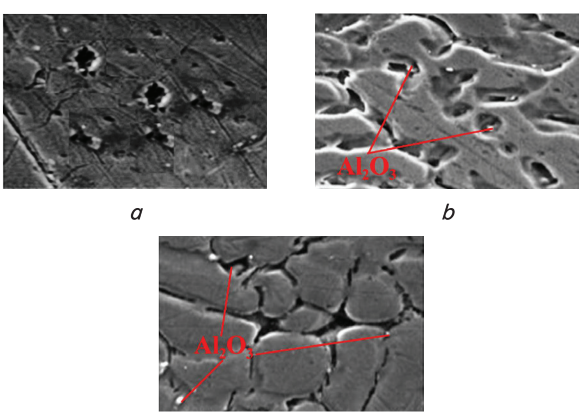
Stress level (MPa)	N_f at 800 °C (ST)	N_f at 850 °C (ST)	N_f at 900 °C (ST)
90	201,000	243,366	207,000
110	155,000	151,100	160,000
130	94,000	84,800	91,800
150	42,800	35,833	33,600
180	10,200	14,266	11,000

Therefore, the S-N curve was plotted depending on the values obtained from the fatigue equations for the three cases (800, 850, and 900 °C) of stirring temperatures as shown above in Fig. 9.

5. 2. Uniformity of AA6061/Al_2O_3 nanocomposites

After preparing the nanomaterials according to weight and inserting them into the alloy, the Al_2O_3 nanoparticles acted as barriers of dislocations leading to an improvement of fatigue behavior and mechanical properties. Moreover, the interaction between the nanoparticles and dislocations plays a significant role in developing the mechanical and fatigue properties [20].

Concerning the scanning electron microscope (SEM) testing, Fig. 11 presents the SEM photographs of *a*: zero-nano at 850 °C, *b*: 9 wt % Al_2O_3 at 850 °C, and *c*: 9 wt % Al_2O_3 at 900 °C.



a *b* *c*

Fig. 11. The main signature: *a* – as received; *b* – 9 wt % Al_2O_3 at 850 °C; *c* – 9 wt % Al_2O_3 at 900 °C (ST), for SEM photographs of AA6061/Al_2O_3

All the 9 wt % Al_2O_3 composites reveal a uniform particle distribution and low agglomeration and few clusters at inter-dendrite regions. However, the best uniformly distributed is 9 wt % Al_2O_3 at 850 °C. Also, adding Al_2O_3 into the base metal melt develops the viscosity of the melt and this retards the movement of Al_2O_3. It is significant to control the solidification rate to attain high distribution of Al_2O_3 in the process of stir casting [21, 22].

6. Discussion of experimental results of determining the effect of stirring temperature (ST) on the AA6061/Al_2O_3 nanocomposite

The findings refer to the improvement of the properties by reassuring that the Al_2O_3 nanoparticles acted as dislocation barriers leading to improved fatigue behavior and mechanical properties. The features of the proposed method indicate that the properties of the new composites give an improvement in the exact case. This was observed in Fig. 5. It is possible to observe the significant increase in ultimate tensile strength (UTS) and yield stress (YS). The results of the VHN hardness of the matrix shown in Fig. 7 can also be observed enhancing up to 16 %, while the ductility enhanced by 36.8 %, as shown in Fig. 8. The maximum enhancement for ultimate tensile strength, yield stress, hardness and ductility occurs when the composite is produced with the addition of 9 wt % of the nanomaterial to a mixture at 850 °C.

This method can be considered a great advantage in improving mechanical properties. But the nature, purity and cost of nanomaterials can be an impediment to successful outcomes. Therefore, research and studies must be conducted to obtain pure and cost-effective nanomaterials.

The limitations of this method can be represented in obtaining a uniform distribution of nanomaterials unless there is an in-depth study of the molecular structure, which enhances the results gained.

One of the focal disadvantages related to nanomaterials is considered to be inhalation exposure. This concern stems from studies in humans that suggest that nanomaterials can cause adverse effects on the lungs. Therefore, caution should be taken when conducting experiments.

The research can be considered useful, as the results have given important indications to the improvement of many properties compared to the untreated alloy. Because of this improvement, this alloy can be used in numerous applications, which use AA6061.

This research is a continuation of many research studies in which many kinds of nanomaterials have been used in different proportions and multiple methods of preparation. These studies were concerned with the improvement of the mechanical properties of alloys. The development of this method can be used for various aluminum alloys, which may enhance the mechanical and fatigue properties with different quantities of nanomaterials depending on the interaction between the aluminum alloys and the ratio of nanoparticles.

7. Conclusions

1. The present investigation revealed with an indication of qualitative or quantitative indicators of research results that the 850 °C stirring temperature with 9 wt % Al_2O_3 compos-

ites provides better mechanical properties, hardness and fatigue properties than the other stirring temperature of 800 °C and 900 °C and the stirring temperature has an important effect on the above properties. The composite with 9 wt % Al_2O_3 stirring at 850 °C exhibits the highest hardness and lowest elongation compared to the other stirring temperature.

2. Analysis of SEM showed evidence for incorporating the Al_2O_3 nanoparticles with the metal matrix. And the AA6069 / wt % Al_2O_3 nanocomposite with 850 °C (ST) exhibited high strength and fatigue life compared to the other produced nanocomposites and base metal.

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References

1. Mohanty, P., Mahapatra, R., Padhi, P., Ramana, C. V. V., Mishra, D. K. (2020). Ultrasonic cavitation: An approach to synthesize uniformly dispersed metal matrix nanocomposites – A review. Nano-Structures & Nano-Objects, 23, 100475. doi: https://doi.org/10.1016/j.nanoso.2020.100475
2. Singh, L., Singh, B., Saxena, K. K. (2020). Manufacturing techniques for metal matrix composites (MMC): an overview. Advances in Materials and Processing Technologies, 6 (2), 441–457. doi: https://doi.org/10.1080/2374068x.2020.1729603
3. El-Mahallawi, I., Shash, A., Amer, A. (2015). Nanoreinforced Cast Al-Si Alloys with Al_2O_3, TiO2 and ZrO2 Nanoparticles. Metals, 5 (2), 802–821. doi: https://doi.org/10.3390/met5020802
4. Iqbal, A., Nuruzzaman, D. M. (2016). Effect of the reinforcement on the mechanical properties of aluminium matrix composite: A review. International journal of applied Engineering research, 11 (21), 10408–10413.
5. Alalkawi, H. J. M., Hamdany, A. A., Alasadi, A. A. (2017). Influence of Nanoreinforced Particles (Al_2O_3) on Fatigue Life and Strength of Aluminium Based Metal Matrix Composite. Al-Khwarizmi Engineering Journal, 13 (3), 91–99. doi: https://doi.org/10.22153/kej.2017.03.005
6. Liu, Z., Mao, W., Zhao, Z. (2006). Effect of pouring temperature on semi-solid slurry of A356 Al alloy prepared by weak electromagnetic stirring. Transactions of Nonferrous Metals Society of China, 16 (1), 71–76. doi: https://doi.org/10.1016/s1003-6326(06)60013-7
7. Haque, S., Ansari, A. H., Bharti, P. K. (2014). Effect Of Pouring Temperature And Stirring Speed On Mechanical, Microstructure And Machining Properties Of Al6061-Cu Reinforced Sicp Metal Matrix Composites. International Journal of Research in Engineering and Technology, 03 (10), 104–109. doi: https://doi.org/10.15623/ijret.2014.0322022
8. Haque, S., Ansari, A. H., Bharti, P. K. (2016). Experimental Evaluation of Process Parameters Effect on Mechanical and Machining Properties of Al6061–Cu–SiCp-Reinforced Metal Matrix Composite. Arabian Journal for Science and Engineering, 41 (11), 4303–4311. doi: https://doi.org/10.1007/s13369-016-2094-6
9. Rajesh, N., Yohan, M. (2016). Recent Studies In Aluminium Metal Matrix Nano Composites (AMMNCs) – A Review. International Journal of Mechanical Engineering and Technology, 7 (6), 618–623.
10. Majdi, H. S., Habeeb, L. J. (2020). Utilizing the Characteristics of Graphene Nano-Platelets to Improve the Cross-Linking Density of a Rubber Nano-Composite. Journal of Nanostructures, 10 (4), 723–735.
11. Al-Wajidi, W., Deiab, I., Defersha, F. M., Elsayed, A. (2018). Effect of MQL on the microstructure and strength of friction stir welded 6061 Al alloy. The International Journal of Advanced Manufacturing Technology, 101 (1-4), 901–912. doi: https://doi.org/10.1007/s00170-018-2957-y
12. Al Alkawi, H. J., Owaidand, A., Kadhim, B. (2018). Characterization of AA 6061–Alloy Composites Reinforced by Al_2O_3 Nano Particles Obtained by Stir Casting. Engineering and Technology Journal, 36 (7A). doi: https://doi.org/10.30684/etj.36.7a.12
13. Al-Salihi, H. A., Mahmood, A. A., Alalkawi, H. J. (2019). Mechanical and wear behavior of AA7075 aluminum matrix composites reinforced by Al2O3 nanoparticles. Nanocomposites, 5 (3), 67–73. doi: https://doi.org/10.1080/20550324.2019.1637576
14. Jiang, J., Xiao, G., Che, C., Wang, Y. (2018). Microstructure, Mechanical Properties and Wear Behavior of the Rheoformed 2024 Aluminum Matrix Composite Component Reinforced by Al_2O_3 Nanoparticles. Metals, 8 (6), 460. doi: https://doi.org/10.3390/met8060460
15. Zhang, Z., Li, Z., Tan, Z., Zhao, H., Fan, G., Xu, Y. et. al. (2021). Bioinspired hierarchical Al_2O_3/Al laminated composite fabricated by flake powder metallurgy. Composites Part A: Applied Science and Manufacturing, 140, 106187. doi: https://doi.org/10.1016/j.compositesa.2020.106187
16. Su, H., Gao, W., Feng, Z., Lu, Z. (2012). Processing, microstructure and tensile properties of nano-sized Al_2O_3 particle reinforced aluminum matrix composites. Materials & Design (1980-2015), 36, 590–596. doi: https://doi.org/10.1016/j.matdes.2011.11.064
17. Kant, S., Verma, A. S. (2017). Stir casting process in particulate aluminium metal matrix composite: a review. International Journal of Mechanics and Solids, 12 (1), 61–69.
18. Alalkawi, H. J. M., Mohammed, A. M., Majid, R. H. (2019). Influence of Stirring Speed on Mechanical Properties for Cast Nano-Particulate AA7075-Al_2O_3 Composites. Al-Nahrain Journal for Engineering Sciences, 22 (2), 109–116. doi: https://doi.org/10.29194/njes.22020109
19. Al-Jaafari, M. A. A. (2021). Study the effects of different size of Al_2O_3 nanoparticles on 6066AA and 7005AA composites on mechanical properties. Materials Today: Proceedings, 42, 2909–2913. doi: https://doi.org/10.1016/j.matpr.2020.12.747
20. Bharath, V., Nagaral, M., Auradi, V., Kori, S. (2014). Preparation of 6061Al-Al_2O_3 MMC's by stir casting and evaluation of mechanical and wear properties. Procedia Materials Science, 6, 1658–1667. doi: https://doi.org/10.1016/j.mspro.2014.07.151
21. Sajjadi, S. A., Ezatpour, H. R., Beygi, H. (2011). Microstructure and mechanical properties of Al–Al2O3 micro and nano composites fabricated by stir casting. Materials Science and Engineering: A, 528 (29-30), 8765–8771. doi: https://doi.org/10.1016/j.msea.2011.08.052
22. Kandpal, B. C., Kumar, J., Singh, H. (2017). Fabrication and characterisation of Al2O3/aluminium alloy 6061 composites fabricated by Stir casting. Materials Today: Proceedings, 4 (2), 2783–2792. doi: https://doi.org/10.1016/j.matpr.2017.02.157